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Whole-Building Hygrothermal Modeling in IEA Annex 41
Towards a new Annex?

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Whole-Building Hygrothermal Modeling in IEA Annex 41

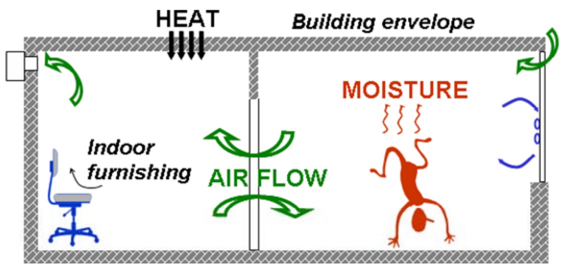
→ Towards a new Annex?

Carsten Rode, Technical University of Denmark

Champs Seminar - La Rochelle, France, July 8, 2008

Whole BEE

Whole building Environmental Engineering



- Proposal for a new IEA Annex
- - or other international cooperative project

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A New Annex ?

Ongoing discussions:

- ...
- *IBPSA, Beijing (Sept. 07)*
- *IEA Annex 41, Porto (Oct. 07)*
- *Buildings X, Clearwater (Dec. 07)*
- ***Nordic Building Physics, Copenhagen (June 08)***
- *Indoor Air, Copenhagen (Aug. 2008)*

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Presentation Outline

- IEA Annex 41 – the history
- Modeling whole building HAM

- What comes after IEA Annex 41?

IEA Annex 41

Whole Building Heat, Air and Moisture Response (MOIST-ENG)

Nov. 2003 – Nov. 2007

Subtasks:

1. Modeling principles and common exercises
2. Experimental Investigations
3. Boundary Conditions
4. Long Term Performance and technology transfer

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Past Progress

Past IEA HAM Activities:

- IEA Annex 14
  - Mould criteria, analysis
- IEA Annex 24
  - HAM theory, material properties, Environmental conditions, Durability & energy.
- IEA Annex 32
  - System approach
- IEA Annex 41
  - Whole building analysis

Annex Participants

Institution	Country
British Columbia Institute of Technology	Canada
Building Research Institute	Japan
Centre de Thermique de Lyon	France
Concordia University Montreal	Canada
Centre Scientifique et Technique du Bâtiment	France
Chalmers Tekniska Högskola	Sweden
Danmarks Tekniske Universitet	Denmark
Eidgenössische Materialprüfungs- und Forschungsanstalt	Switzerland
Fraunhofer Gesellschaft	Germany
Glasgow Caledonian University	United Kingdom
Kinki University	Japan
Kungliga Tekniska Högskolan	Sweden
Katholieke Universiteit Leuven	Belgium
Kyoto University Japan	Japan
Lund Tekniska Högskola	Sweden
National Institute for Land and Infrastructure Management	Japan
National Research Council	Canada
Norges Teknisk-Naturvitenskapelige Universitet	Norway
Oak Ridge National Laboratory	United States
Pontificia Universidade Catolica Do Parana	Brasil
Slovenska Akademia Vied	Slovakia
Danish Building Research Institute	Denmark
Sekisui House Corporation	Japan
Sveriges Provnings- och Forskningsinstitut	Sweden
Technion Israel Institute of Technology	Israel
Tohoku University	Japan
Tallinna Tecnikaülikool	Estonia
Tampereen Teknillinen Yliopisto	Finland
Technische Universität Dresden	Germany
Technische Universiteit Eindhoven	The Netherlands
Technische Universität Wien	Austria
University College London	United Kingdom
Universidade Da Coruña	Spain
Universidade Federal de Santa Catarina	Brasil
Universiteit Gent	Belgium
Université de La Rochelle	France
University of Saskatchewan	Canada
Universidade do Porto	Portugal
Technical Research Center	Finland

- 39 institutions
- 19 countries

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Objectives have been met by:

- **Theoretical analysis**
- **Computer model development**
- **Application of engineering tools**
- **Benchmarking and Common Exercises**
- **Parameter analysis and making considerations about which details are important (and which not)**

Extension of **building component** simulation tools

HAM modeling

Improve **existing building simulation** tools (transfer in the envelope)

Combination of both

IEA Annex 41 / Subtask 1 should not develop one common tool

Software used/developed

Name	Developer	Main user in Annex 41	Availability	Origin	Possibility of adding new components	Remarks
BSim	Danish Building Research Institute (Denmark)	Technical University of Denmark	Commercial program	Energy	No	
BUILDOPT-VIE	Vienna University of Technology	Vienna University of Technology	Research program	Energy	-	-
Clim2000 3.2.0	EDF (Electricité de France)	Centre de Thermique de Lyon - CETHL, (France)	Research program, not commercially available	Energy	Yes	Core program on Unix workstations
DELPHIN 4.5	TU Dresden, (Germany)	TU Dresden	Research program, commercial version available	Envelope	No	
EnergyPlus v1.2.1	Department of Energy (USA)	University College London, (UK)	Freeware	Energy	Yes	
ESP-r		ICA SAS	Freeware	Energy	Yes	
NPI	ICA SAS (Slovakia)	ICA SAS	Research program	Envelope	Yes	
IDA-ICE	EQUA Simulation AB, (Sweden)	Tallinn University of Technology, (Estonia)	Commercial program	Energy	Yes	The code is open
HAMFitPlus	Concordia University, (Canada)	Concordia University,	Personal Research program (F. Tariku)	HAM whole building	Yes	Requires Matlab/ Simulink and Comsol
HAMLab (Heat Air & Moisture Laboratory)	Eindhoven University of Technology (Netherlands)	Eindhoven University of Technology	Freeware	Energy	Yes	Requires Matlab/ Simulink and Comsol
HAM-Tools	Chalmers University of Technology (Sweden)	Chalmers University of Technology, CETHIL	Freeware	HAM whole building	Yes	Requires Matlab/ Simulink
PowerDomus	LST at the Pontifical Catholic University of Parana - PUCPR, (Brazil)	PUCPR	Not ready for distribution	Envelope	No	
SPARK 2.01	LEPTAB, University of La Rochelle (France)	LEPTAB	Freeware	Energy	Yes	Possible couplings with EnergyPlus
TRNSYS 16.00	University of Wisconsin, Madison, (USA)	University of Gent (Belgium) PUCPR, CETHIL	Commercial program	Energy	Yes	Possible coupling with COMIS
TRNSYS ITT	Solar Energy Lab (University of Wisconsin), TU Dresden, (Germany)	TU Dresden, Germany	Research program	Energy	Yes	All features of TRNSYS available
WUFI-Plus	Fraunhofer-Institut für Bauphysik, (Germany)	Fraunhofer-Institut für Bauphysik	Commercial program	Envelope	Yes	
Xam	Kinki University, Japan	Kinki University, Japan	Personal product by A. Iwamae	Energy	No	Personal use by the author

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Common Exercises

CE0 Cethil, France

Validation of thermal aspects of the employed models by repeating BESTEST

CE1 DTU, Denmark

CE0 + moisture interactions between constructions and indoor climate

CE2 Tohoku University, Japan

Experimental data from climate chamber tests (airflow)

CE3 FhG, Germany

Double chamber test under real condition

CE4 CETHIL, INSA-Lyon, France

Extension of CE3 with focus on energy efficient moisture management

CE5 KUL, Belgium

Real life row house, documented moisture damage - growing complexity

Common Exercises

CE0 **Cethil, France**
Validation of thermal aspects of the employed models by repeating BESTEST

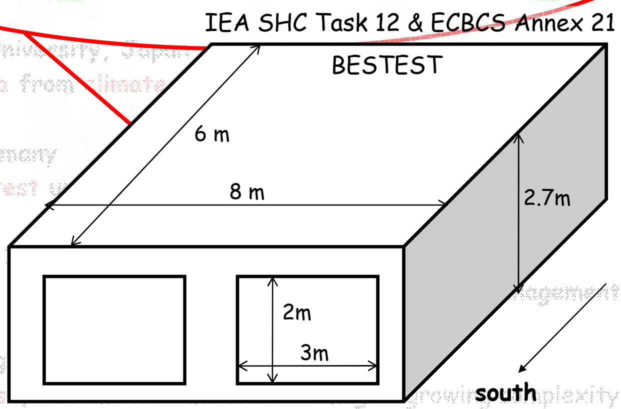
CE1 **DTU, Denmark**
CE0 + moisture interactions between constructions and indoor climate

CE2 Tohoku University, Japan
Experimental data from climate

CE3 FhG, Germany
Double chamber test

CE4 CETHIL,
Extension of CE3

CE5 KUL, Belg
Real life row hous



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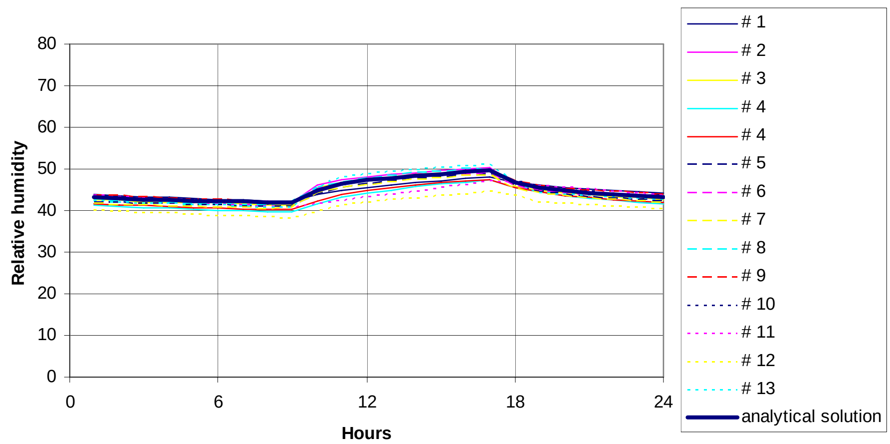
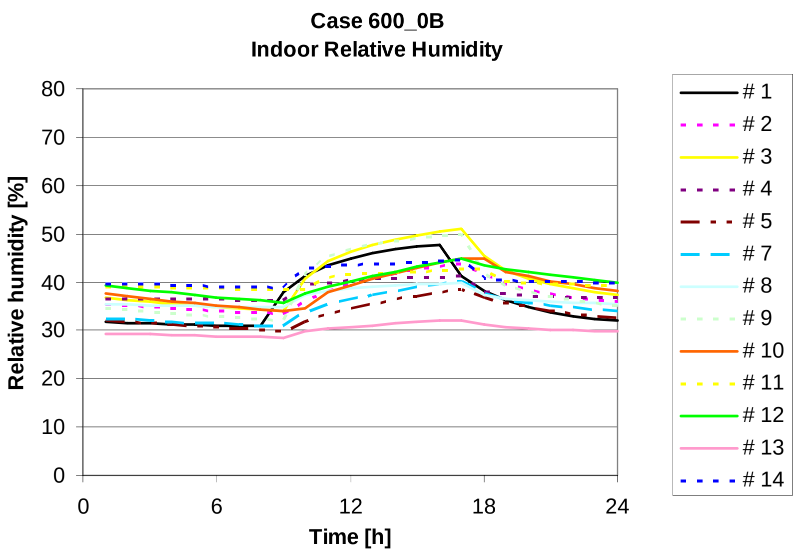
RESULTS: CE1A

CE1A Case 0B: open indoor surface
NUMERICAL RESULTS
Indoor Relative Humidity



Numerical vs. analytical calculations. Isothermal. Monolithic construction with open surfaces.

RESULTS: CE1 600_0B (RH indoor)



Analytical calculations. Isothermal. Construction surfaces are open.

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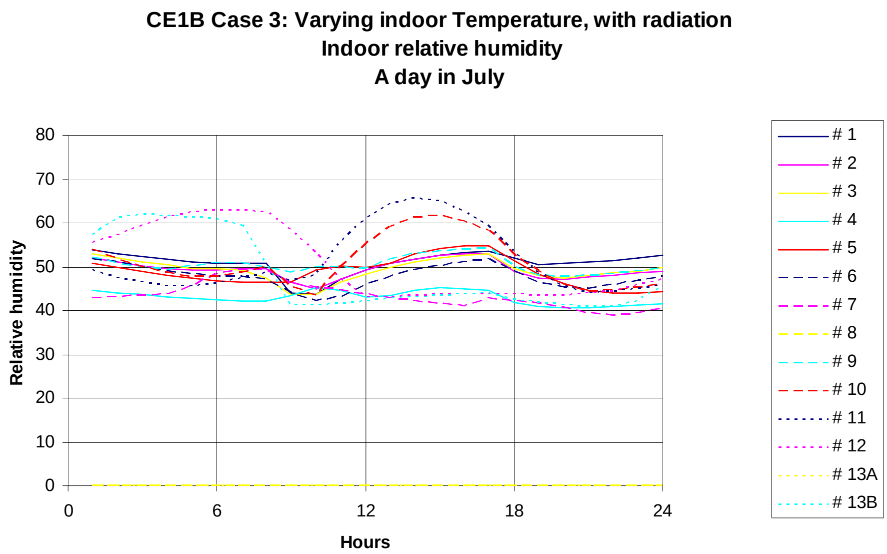
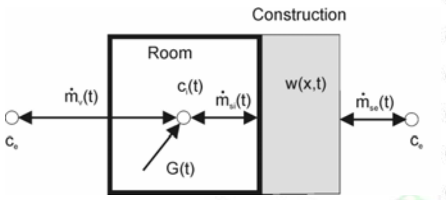
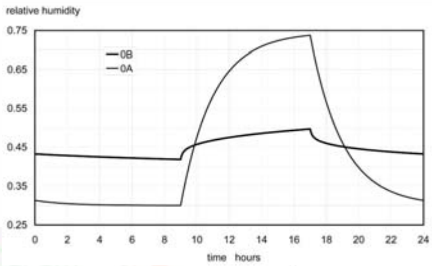
RESULTS: CE1B Case 3 (indoor RH)



Numerical calculations. Varying indoor temperature. Monolithic construction. With solar gain.

Analytical solutions – Moisture in rooms





Solution without moisture transfer to the construction

$$c_i(t) = c_e + \frac{G}{n \cdot V} + \left(c_{i0} - c_e - \frac{G}{n \cdot V} \right) \cdot e^{-n \cdot (t - t_0)} \quad t \geq t_0$$

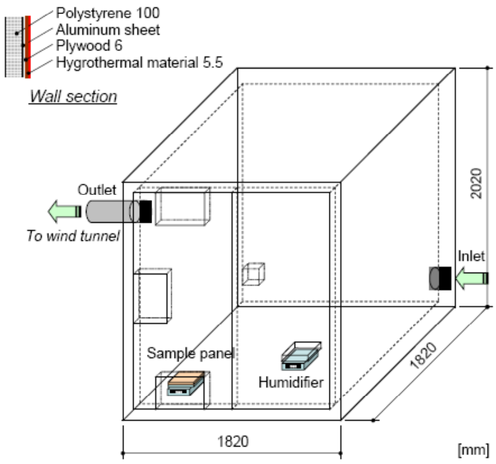
Solution with moisture transfer to the construction

$$c_n(t) = \frac{G_{0,n}}{R_a} \cdot \left(1 - \left(1 - \frac{d_s}{d_2} \right) \cdot e^y \cdot \mathrm{erfc}\left(\sqrt{y} \right) \right)$$

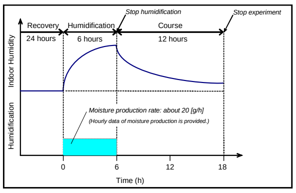
Bednar & Hagentoft

Common Exercise 2

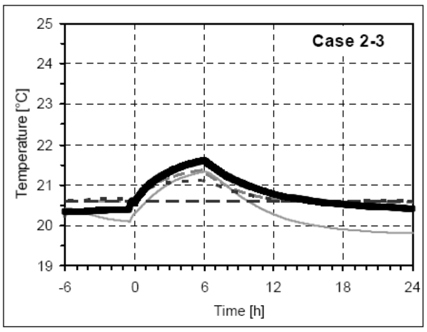
Based on experimental data from climate chamber tests at Tohoku University, Japan. The tests had known wall claddings and air flow conditions.



	Hygrothermal materials	Target of ventilation rate [1/h]
Case 2-1	all walls, ceiling, floor	1.0
Case 2-2	floor	
Case 2-3	one side of walls	
Case 2-4	3 sides of walls	
Case 2-5	ceiling	
Case 2-6	none	



CE2 - Some Results



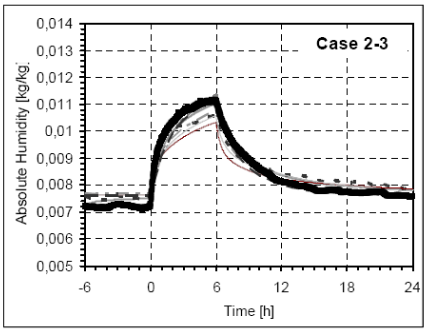


Figure 4.4.8 Comparison between measured values and simulation results (Case 2-3)

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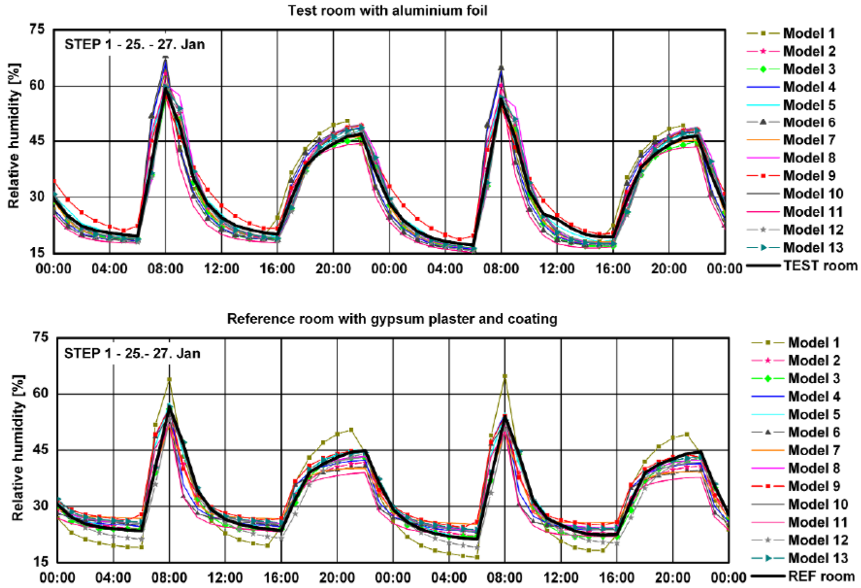
Common Exercise 3

Based on double climatic chamber tests carried out by the Fraunhofer Institut für Bauphysik, Germany, using two identical chambers with different cladding materials.

foil faced test room

reference room

CE3 – Step 1 - RH



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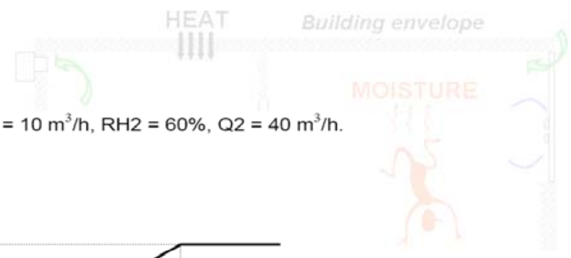
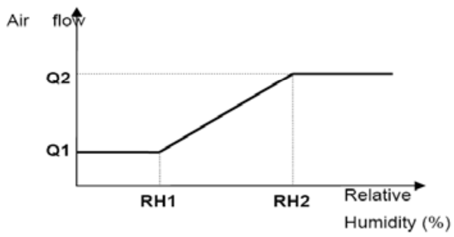
Common Exercise 4

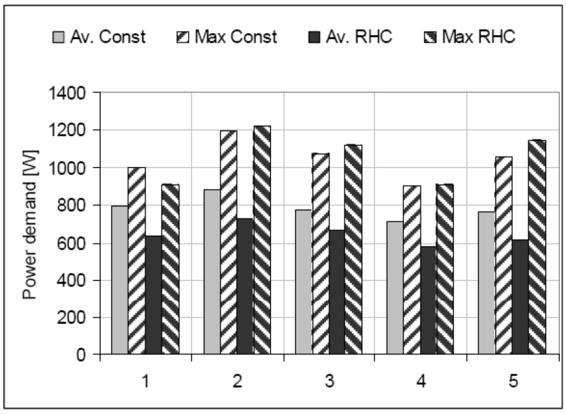
CE3 with RH controlled ventilation



RH1 = 25%, Q1 = 10 m^3/h, RH2 = 60%, Q2 = 40 m^3/h.



CE 4 - Power Demand



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Common Exercise 5

CE 2: Ba ... ber
tests at ... own
wall clad...

CE 3: Ba ... d out
by the F ... using
two iden ... rials.

CE4: C...
Extensio ... sture
managem...

CE 5. Based on data from a real life row house located in Belgium. With some known indoor climate/moisture problems which also involve effects of adventitious airflow.

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CE 2: Bas … e chamber
tests at To … ve known
wall cladd …

CE 3: Bas … carried out
by the Fra … any, using
two identi … materials.

CE 6. A two-storey climatic chamber test carried out at Concordia University, Canada, has served as basis for this exercise.

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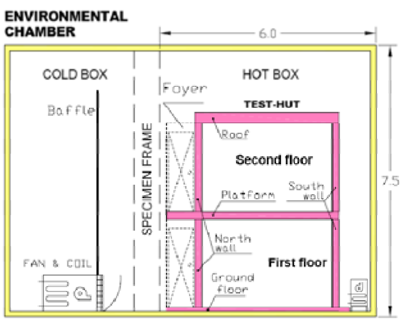
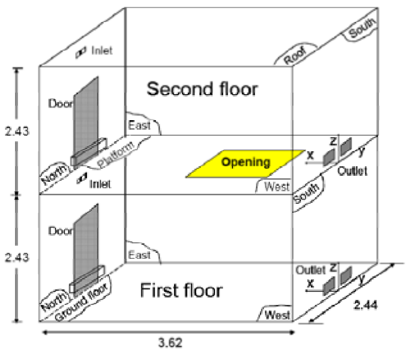
Common Exercise 6





Objective of the experimental study:

- to generate reliable datasets to advance the understanding of the whole building response to heat, air, and moisture (HAM),
- to validate ongoing and future numerical models

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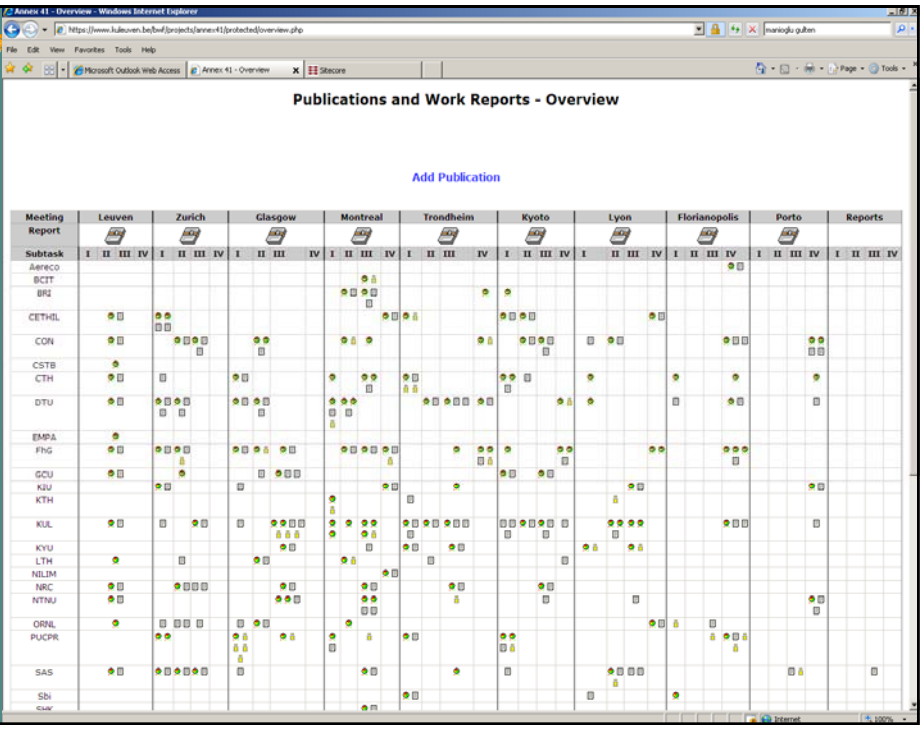

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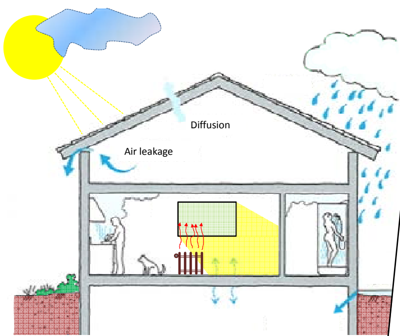
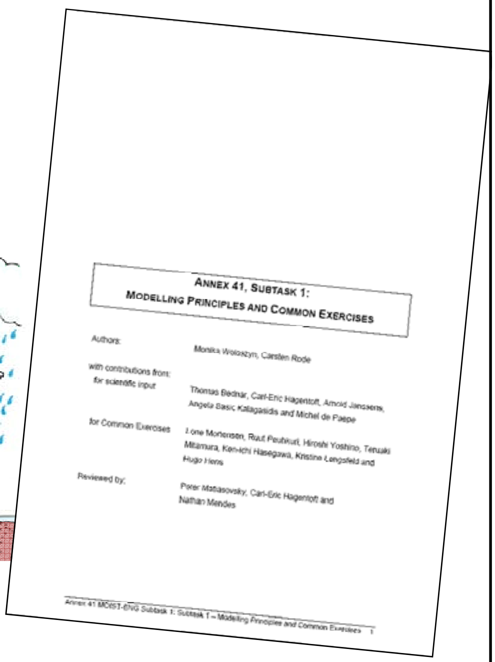
Final Report:





ANNEX 41, SUBTASK 1:
MODELLING PRINCIPLES AND COMMON EXERCISES

Authors: Monika Woloszyn, Carsten Rode

with contributions from:
for scientific input: Thomas Bednar, Carl-Eric Hagentoft, Arnold Janssens, Angela Sasic Kalagasidis and Michel de Paepe

for Common Exercises: Lone Mortensen, Ruut Peuhkuri, Hiroshi Yoshino, Tetsuaki Mitamura, Ken-ichi Hasegawa, Kristine Lengsfeld and Hugo Hens

Reviewed by: Peter Matiasovsky, Carl-Eric Hagentoft and Nathan Mendes

Annex 41 MOIST-ENG Subtask 1: Subtask 1 – Modelling Principles and Common Exercises 1

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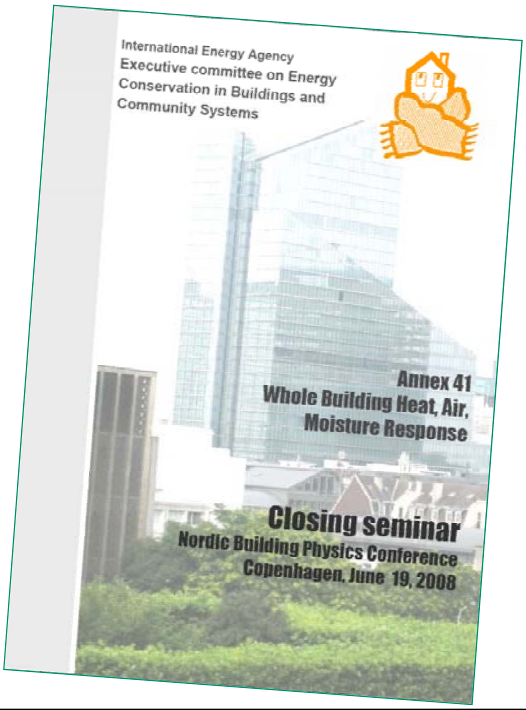

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A critical review of past/recent activity

- Good in 1D diffusion modeling
- Now getting better in capillary moisture analysis
- Very limited in air flow modeling (Fundamentals, System, and Sub-system effects)
- Very crude in whole building
- Crude in IAQ modeling

Relation to Energy & Durability Limited

Achilles Karagiozis at IEA Annex 41 Closing Seminar, Lyngby, June 19, 2008

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A New Annex ?

What's next?

~~More of the same...~~

- Emission & IAQ modelling
- Surface chemistry
- Durability
- Stochastic analysis
- Risk assessment
- Generation of "damage functions"
- Impact of climate change
- Buildings for developing countries & their climates

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A New IEA Annex ?

- ***Energy !***
- *Internationally coordinated national initiatives (e.g. national centres of excellence)*
- *Industry funded activities*
- *EU-funded*
- *Combinations...*

Background of New Annex

- Existing models allow for the prediction of several aspects related to climatization of buildings including energy performance, building physics, thermal indoor climate, and to a limited extent indoor air quality.
  → Integrated Design
- IEA Annex 41 one Whole Building Heat, Air and Moisture Transfer is coming to an end by the end of 2007. The project has been successful in stimulating a lot of new integrated model development on the building physics side.
- New endeavours in indoor environmental research and knowledge on the impact of materials (emissions) on the IAQ…
- There is a strong need to link the building physics activities to the IEQ activities.
- Prospect (in terms of energy and sustainability issues):
  It is necessary to tie in this knowledge in order to reach towards future goals of ***passive / near zero energy consuming buildings*** while still maintaining ***good indoor climates for human activity, well-being and high productivity and learning***.

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Combined Heat, Air, Moisture & "Something"

- State of the art
  - HAM
  - VOC emissions
  - Durability
  - Energy
  - Sustainability
  - Impact of climate change
- Further research needs
  - Refinement of mechanistic models
  - Integration of current knowledge
  - Data
  - …
- Scope for research
  - Application, modelling tool and targeted fundamentals

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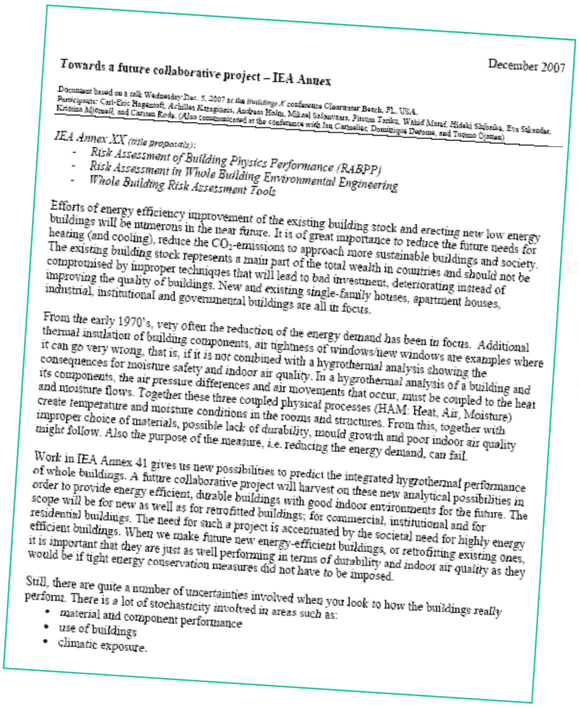

Towards a future collaborative project – IEA Annex December 2007

Document based on a talk Wednesday Dec. 5, 2007 at the *Buildings X* conference Clearwater Beach, FL, USA. Participants: Carl-Eric Hagentoft, Achilles Karagiozis, Andreas Holm, Mikael Salonvaara, Fitsum Tariku, Wahid Maref, Hideki Shibaike, Eva Sikander, Kristina Mjörnell, and Carsten Rode. (Also communicated at the conference with Jan Carmeliet, Dominique Derome, and Tuomo Ojanen)

IEA Annex XX (title proposals):

- *Risk Assessment of Building Physics Performance (RABPP)*
- *Risk Assessment in Whole Building Environmental Engineering*
- *Whole Building Risk Assessment Tools*

Efforts of energy efficiency improvement of the existing building stock and erecting new low energy buildings will be numerous in the near future. It is of great importance to reduce the future needs for heating (and cooling), reduce the CO_2-emissions to approach more sustainable buildings and society. The existing building stock represents a main part of the total wealth in countries and should not be compromised by improper techniques that will lead to bad investment, deteriorating instead of improving the quality of buildings. New and existing single-family houses, apartment houses, industrial, institutional and governmental buildings are all in focus.

From the early 1970's, very often the reduction of the energy demand has been in focus. Additional thermal insulation of building components, air tightness of windows/new windows are examples where it can go very wrong, that is, if it is not combined with a hygrothermal analysis showing the consequences for moisture safety and indoor air quality. In a hygrothermal analysis of a building and its components, the air pressure differences and air movements that occur, must be coupled to the heat and moisture flows. Together these three coupled physical processes (HAM: Heat, Air, Moisture) create temperature and moisture conditions in the rooms and structures. From this, together with improper choice of materials, possible lack of durability, mould growth and poor indoor air quality might follow. Also the purpose of the measure, i.e. reducing the energy demand, can fail.

Work in IEA Annex 41 gives us new possibilities to predict the integrated hygrothermal performance of whole buildings. A future collaborative project will harvest on these new analytical possibilities in order to provide energy efficient, durable buildings with good indoor environments for the future. The scope will be for new as well as for retrofitted buildings; for commercial, institutional and for residential buildings. The need for such a project is accentuated by the societal need for highly energy efficient buildings. When we make future new energy-efficient buildings, or retrofitting existing ones, it is important that they are just as well performing in terms of durability and indoor air quality as they would be if tight energy conservation measures did not have to be imposed.

Still, there are quite a number of uncertainties involved when you look to how the buildings *really* perform. There is a lot of stochasticity involved in areas such as:

- material and component performance
- use of buildings
- climatic exposure.

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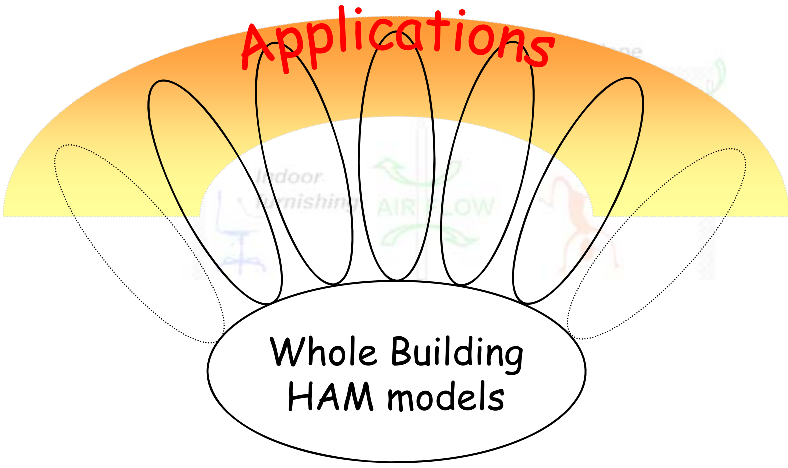
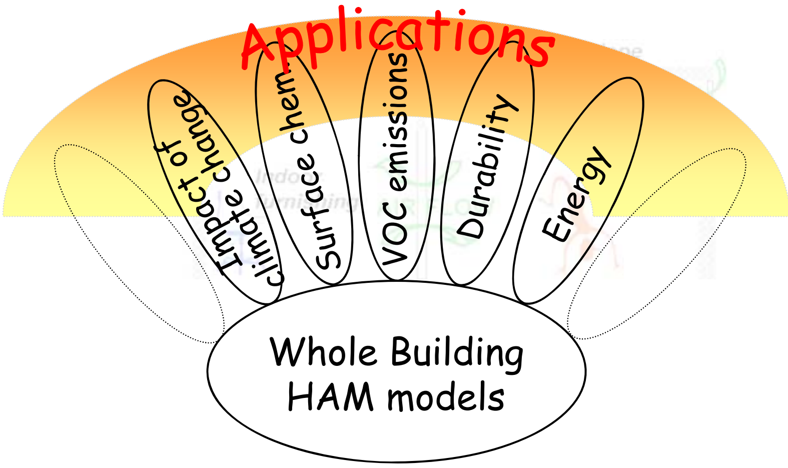
Whole Building Environmental Modelling (Whole BEE)



Whole Building Environmental Modelling (Whole BEE)



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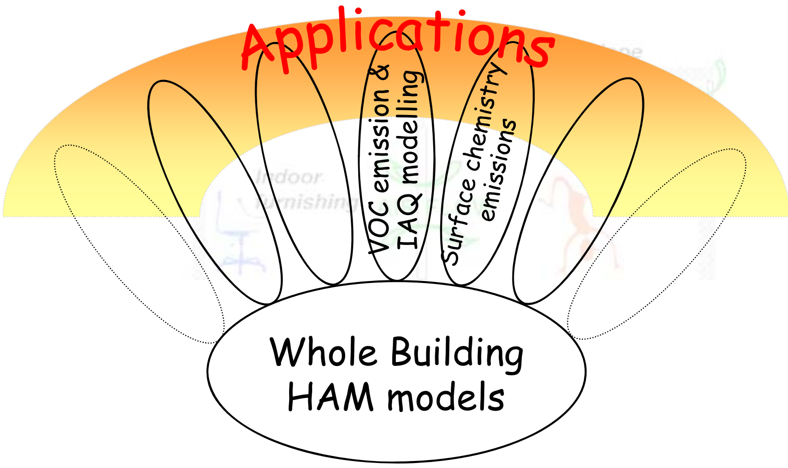
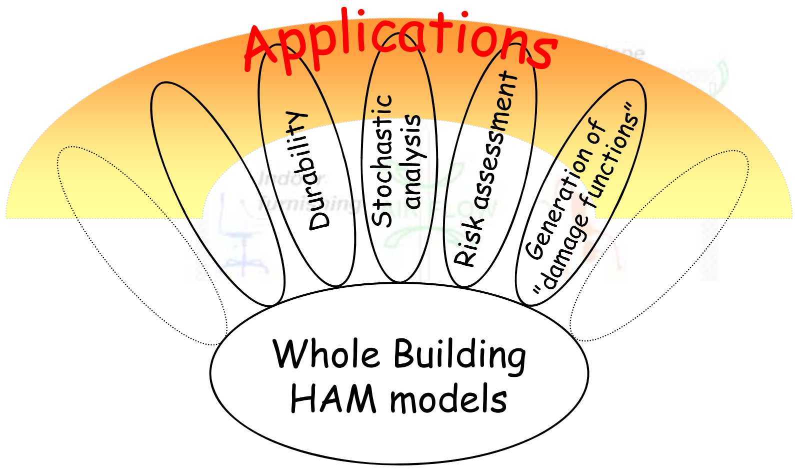
Whole Building Environmental Modelling (Whole BEE)



Whole Building Environmental Modelling (Whole BEE)



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Need Multiple Annexes

- Statistical Analysis
- Risk Assessment
- Fill in the gaps

ENERGY

Input coordinated by:
Prof. Carl-Eric Hagentoft,
Chalmers Univ., Sweden

- Indoor Env. perf.
- HAM
- VOC / Surf chem.

ENERGY

Input coordinated by:
Assoc. Prof. Carsten Rode,
Techn. University of Denmark

Possible Funding / Framework

- IEA (nationally funded)
- EU
- National research foundations